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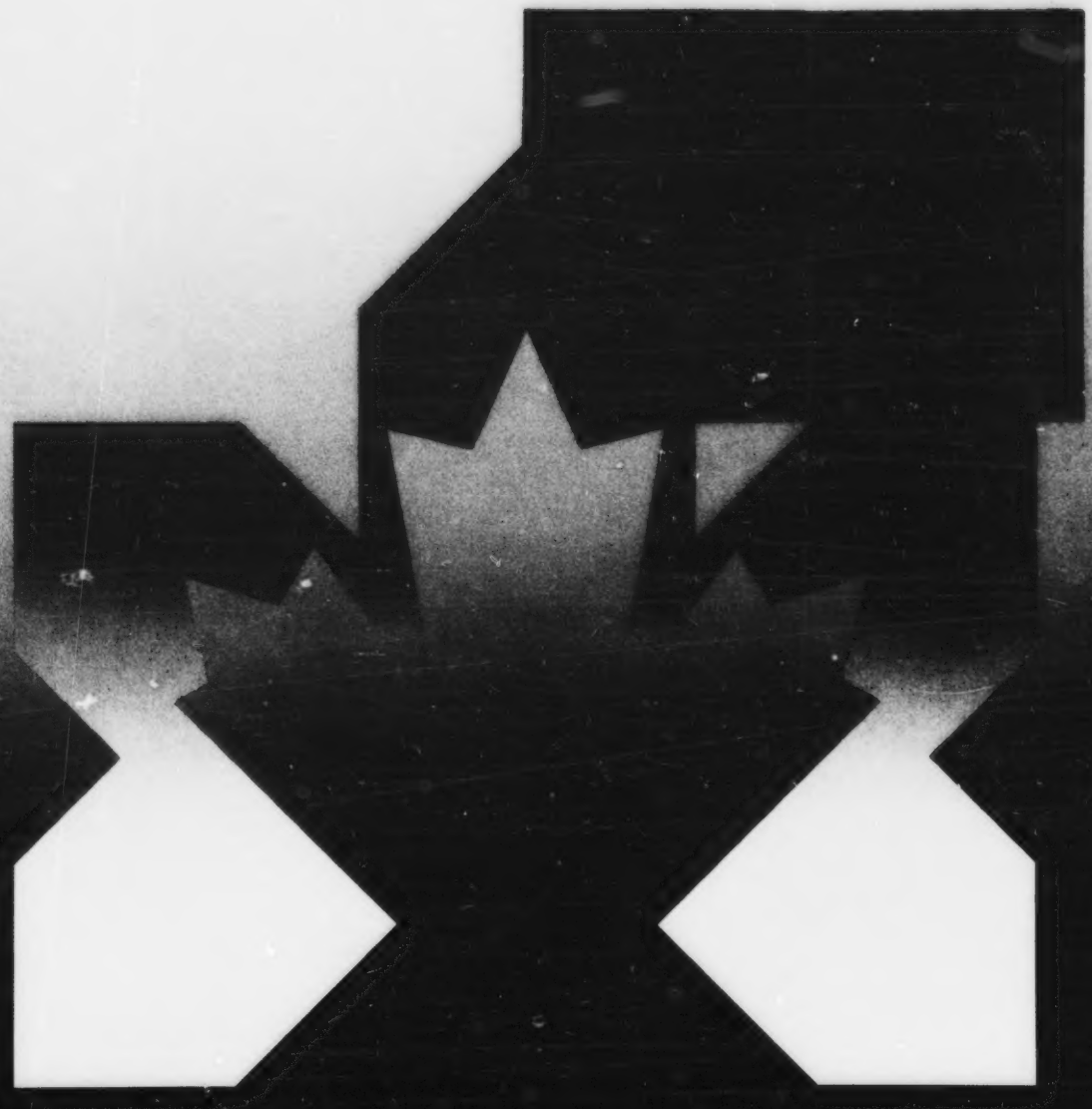

Canada

91-05044/

# USERS' GUIDE TO CATHODIC PROTECTION OF REINFORCED CONCRETE PARKING STRUCTURES

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Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part IX of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may abe useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

## CAUTION

The information contained in this report is based upon a review of the literature, discussions with building owners and with suppliers of cathodic protection systems, and the authors' direct experience with several installations. It is believed to be current at the time of writing. Ongoing developments will likely improve the technical understanding of the processes involved and create new products. These factors may in future affect the validity of some of the contents of this report.

The funding for this report was provided by Canada Mortgage and Housing Corporation, but the contents represent the authors' review of available literature and no responsibility for them should be attributed to the Corporation.

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# 1. INTRODUCTION

## 1.1 General

This document is intended to provide building owners and managers with a general understanding of the principles involved in the use of cathodic protection for corrosion damaged, reinforced concrete parking structures.

The primary cause of the structural deterioration of parking structures is corrosion of the embedded reinforcing steel. An extensive technical evaluation of the facility and a subsequent economic comparison of alternative repair strategies is required before a repair program can be designed. Such a program typically has two basic objectives:

1) reinstate the structural integrity of the facility
2) control future corrosion

Corrosion of steel in concrete can be caused either by exposure to air and water or to concrete affected by carbonation; or by electrochemical corrosion, which occurs in chloride-contaminated concrete. For electrochemical corrosion to occur, anodes (corrosion sites) and cathodes (non-corrosion sites) must be formed at different locations along the surface of the steel and an electrolyte (concrete) must exist between them (see Figure 1). This chloride-induced corrosion represents the major cause of damage in parking structures.

Cathodic protection is specifically intended to reduce the rate of electrochemical corrosion to a minimal level. It does not restore any lost structural capacity or treat other types of corrosion. Cathodic protection must therefore be seen as only one of many possible components in a repair program, all of which must be compatible for the program to be successful.

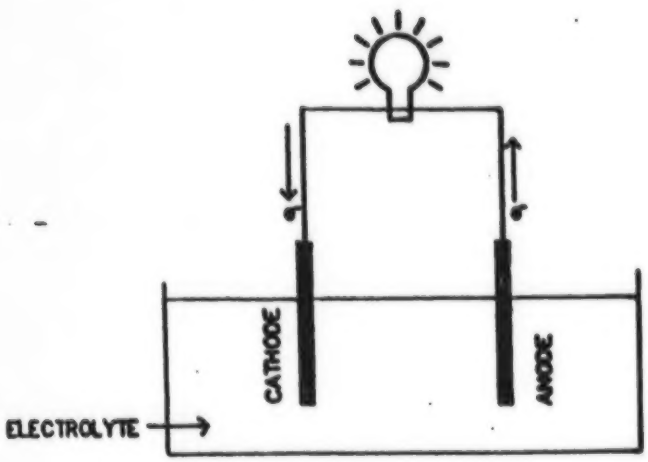



FIG. 1 ELECTROCHEMICAL CELL

A potential purchaser should have a basic knowledge of the theory and application of cathodic protection in order to make an informed decision about its use because there are no generally accepted standards for cathodic protection of reinforced concrete, there is no way to visually assess whether a system is performing acceptably, and cathodic protection is not technically and economically appropriate for all corroding structures. This report is not intended to provide information about the other treatment options available, or about the methods of comparison. The evaluation of options should be made with the involvement of a knowledgeable specialist. Further details are available in the CMHC document "A Report on the State of the Art of Cathodic Protection Systems for the Rehabilitation of Concrete Parking Structures".

## 1.2 Corrosion Mechanism

In uncontaminated concrete, the iron in steel reacts with oxygen and water in the pores of concrete to form a stable "passive layer" on the surface of the steel. Rust will not form where a passive layer is intact, which means that most reinforced concrete structures do not suffer corrosion damage.

Chlorides from road salt (sodium chloride) are absorbed by the pore water in concrete from slush melting off cars or from de-icers applied directly to the slab. Chlorides are also contained in some aggregates (sand and stone) used in the manufacture of concrete. Pore water can also be contaminated by calcium chloride, which is an admixture sometimes used to accelerate the strength gain of concrete. At high enough concentrations, the chloride interferes with the passive layer on the steel. This interference allows "rust" to form. (See Figure 2 for a summary of the reactions involved.)

Rust has a larger volume than iron. This increase in volume causes pressure within the concrete. If the stresses produced exceed the concrete strength, the concrete will fracture. Fractures radiate from the

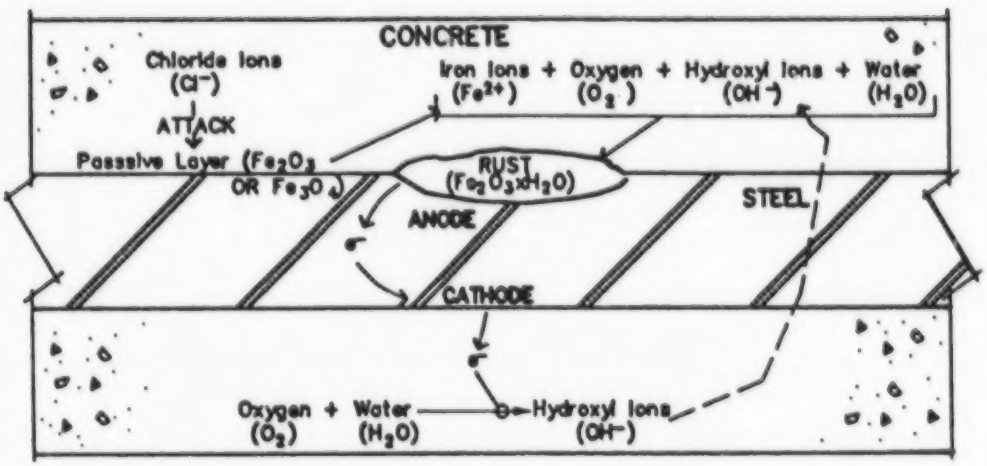



FIG 2. ELECTROCHEMICAL CORROSION MECHANISM OF STEEL IN CHLORIDE CONTAMINATED CONCRETE.
(NOT ALL CHEMICAL REACTIONS ARE INCLUDED)

steel in a pattern that can lift the surface of the concrete. This separation is called a delamination.

If the steel and concrete had uniform properties at all locations, no corrosion cells would form. The various conditions which do create differences, however, include

- oxygen and moisture content of the concrete pores
- chloride content of the concrete pore water
- microscopic composition of the steel
- voids formed beneath the steel as concrete settles during placement

If different conditions exist across microscopic distances, usually on the same bar, "microcells" are formed (see Figure 3). If there are larger distances (several millimetres or more) between the anode and cathode, for example between the top layer of steel encased in concrete with high chloride levels from road salt and the bottom layer with low chloride levels, a macrocell exists. It is not known which type of cell creates more damage, or how they interact in reinforced concrete.

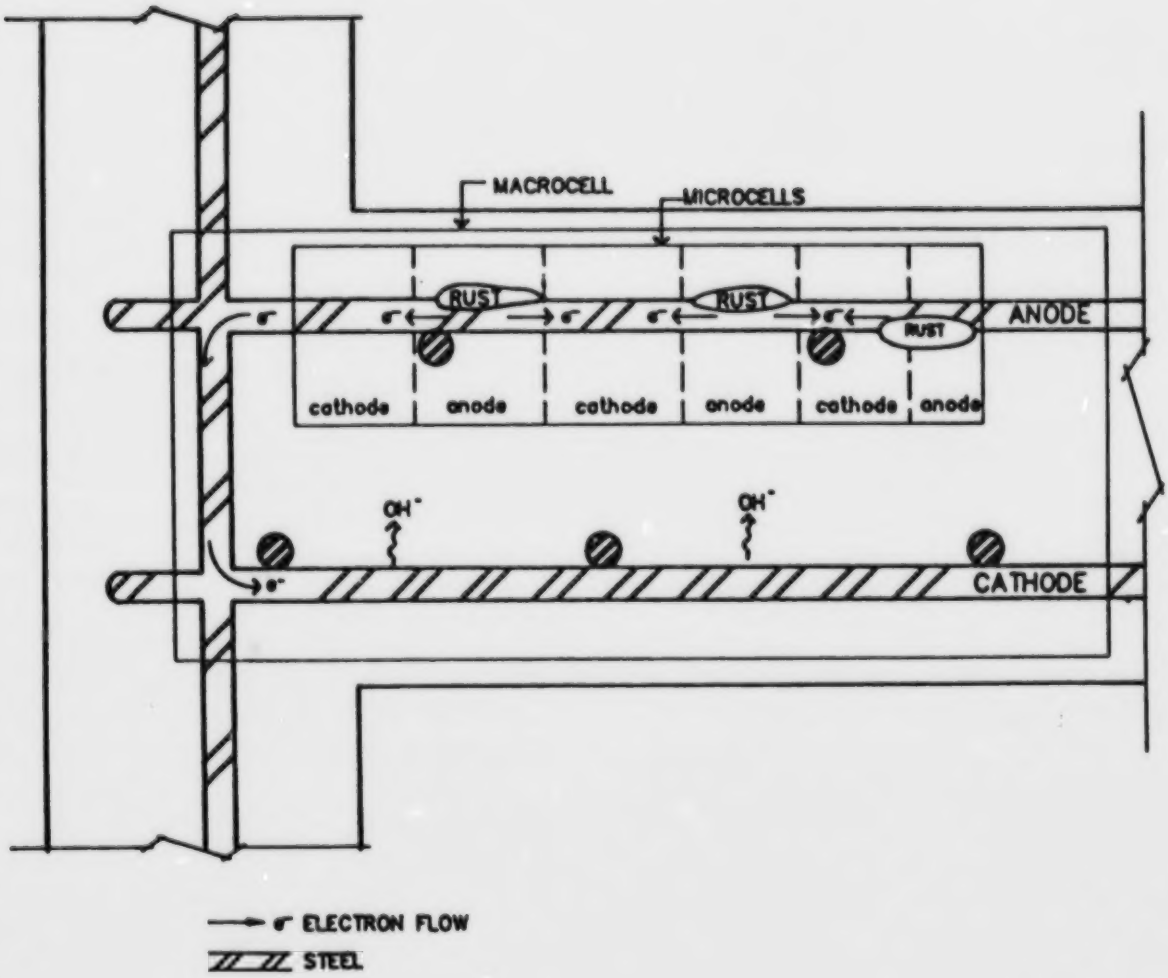



FIG 3. SCHEMATIC DIAGRAM OF MACROCELL AND MICROCELL CORROSION CELLS IN REINFORCED CONCRETE STRUCTURES CONTAMINATED BY CHLORIDES.
( MICROCELLS ARE ACTUALLY VERY SMALL)

## 2. CATHODIC PROTECTION

### 2.1 Theory

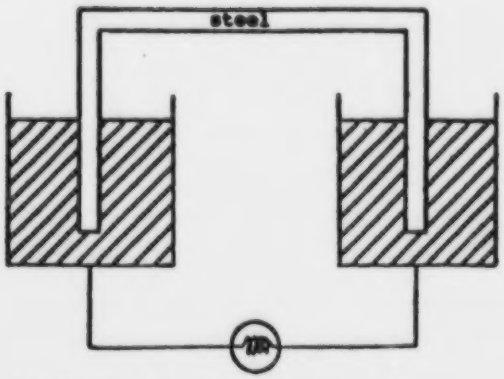
The scientific theory of cathodic protection is well established, but the technology of its application to reinforced concrete is not. The process used in concrete is impressed current cathodic protection. The relationship between cathodic protection and corrosion is given in Figure 4. Figure 5 is a schematic diagram of the reactions in the reinforced concrete. One pole of an external direct current power source is connected to the steel and the other to a conductive layer (anode) applied to the surface of the concrete. The applied voltage causes current to flow from the anode to the concrete and from the concrete into the steel. The corrosion reaction occurs where current leaves a surface. Cathodic protection moves this reaction from the steel/concrete interface to the interface between the concrete and the anode. It involves "consumption" of the new anode, instead of the steel, at a rate which is related to the amount of current flowing through the system.

The following three descriptions are given as alternative methods of understanding the process:

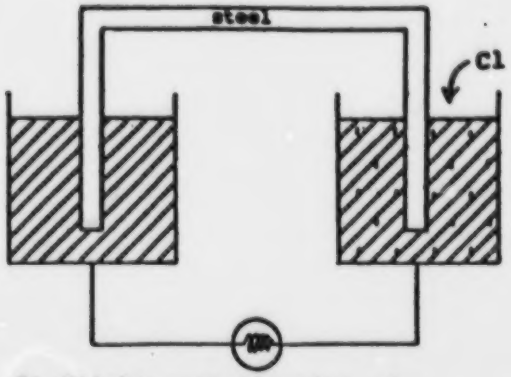
1. The conversion of iron to rust involves iron ions "losing" electrons. If the steel is "flooded" with electrons (from the negative pole of a direct current power supply), the iron will not "lose" electrons and will not rust.

2. The corrosion process requires different locations on the reinforcing steel to be anodic and cathodic. By making all the steel receive current from the concrete, the number of anodic sites, and therefore the amount of corrosion, can be made negligible.

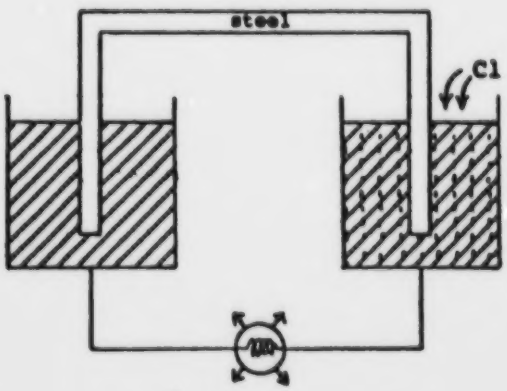
3. The potential for corrosion at the steel/concrete interface can be reduced by creating a higher corrosion potential at a new anode connected to the concrete.



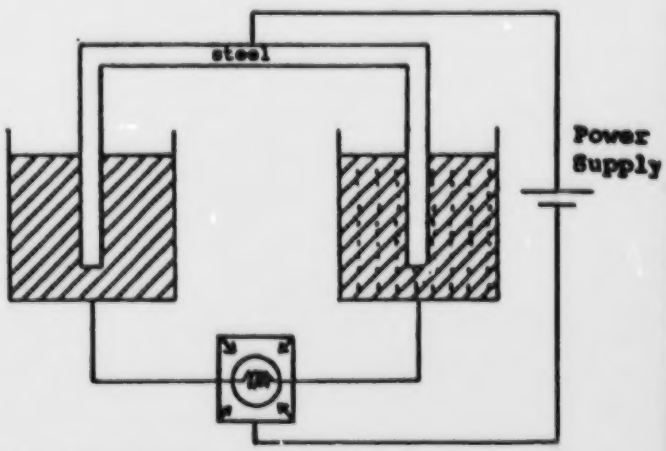

1) Steel in uncontaminated concrete - same electrodes, same electrolyte - no current




2) Slight contamination of 1 electrolyte, not enough difference for current flow




3) Significantly greater contamination of electrolyte, corrosion reaction at anode, electric current flows between electrodes




4) Cathodic Protection

FIG. 4 CORROSION CELL & CATHODIC PROTECTION

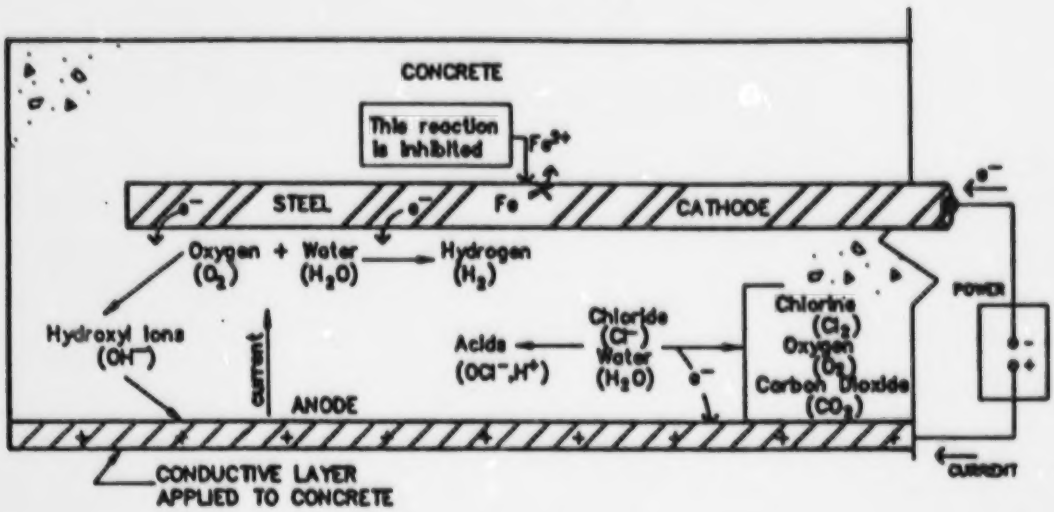



FIG. 5. SCHEMATIC DIAGRAM OF IMPRESSED CATHODIC PROTECTION OF STEEL IN CONCRETE.

NOTES: CHLORINE GENERATION ONLY AT ANODE VOLTAGES OVER ABOUT 1V (CSE)
: $OCl^-$= HYPOCHLOROUS ACID

## 2.2 Practical Considerations in Reinforced Concrete Structures

### 2.2.1 Concrete as an Electrolyte

The conductivity of concrete, and therefore the amount of protective current reaching a local section of reinforcing steel, varies with the amount of moisture and chloride in the concrete. This variability can make control and performance measurement of the overall system difficult.

### 2.2.2 Reactions at the Reinforcing Steel (Cathode)

The cathodic reactions increase the alkalinity of the concrete, which favours the formation of a passive film on the steel. This counteracts the effect of chloride ions. Chloride ions are also drawn away from the steel by the impressed current of cathodic protection. At sufficient current levels, hydrogen can be evolved at the steel. This can cause brittleness in some prestressing steels. For this reason cathodic protection has not been used on prestressed structures.

### 2.2.3 Reactions at the Anode

Products of the anode reaction are an acid, chlorine gas, oxygen and/or carbon dioxide. At sufficient current density, acid-induced cracking of the concrete near the anode has occurred around embedded carbon based anodes. In most installations, however, the current densities are too low to produce significant quantities of these products.

### 2.2.4 Discontinuous Steel

For a structure to be protected, all of the steel must be at the same potential, and which requires the individual bars to be electrically connected. If this is not the case, or if loose pieces of metal are dropped into the forms during construction, anodes and cathodes will be created on the discontinuous steel. Corrosion will occur at the anode sites and could lead to delamination (see Figure 6). General continuity of the reinforcing steel can be checked with a half-cell connected to different locations on the steel. This does not identify small pieces of discontinuous metal, and these have been a problem for many installations.

### 2.2.5 Short Circuits

The ends of wires used to tie rebar in place during construction and metallic supports holding the rebar off the forms are often exposed at the surface of the slab. Both of these are primary causes of short circuits between the conductive layer on the surface and the reinforcing. These short circuits cause two problem: they reduce the amount of current flowing through the electrolyte, and because the metal is in contact with the anode, it will corrode. Various procedures are being used to locate short circuit paths, including electric arc brushes before installation and thermography after installation. Once located, the short circuit can be electrically isolated from the anode (but the metal could still be discontinuous). Short circuits remain a serious problem for systems with anodes applied to the bottom surface of the slab.

## 2.3 Condition Survey Requirements

### 2.3.1 Corrosion Potentials

A half-cell corrosion potential survey of the slab is required in order to assess whether or not cathodic protection should be considered as a possible treatment strategy. The primary method of evaluating cathodic

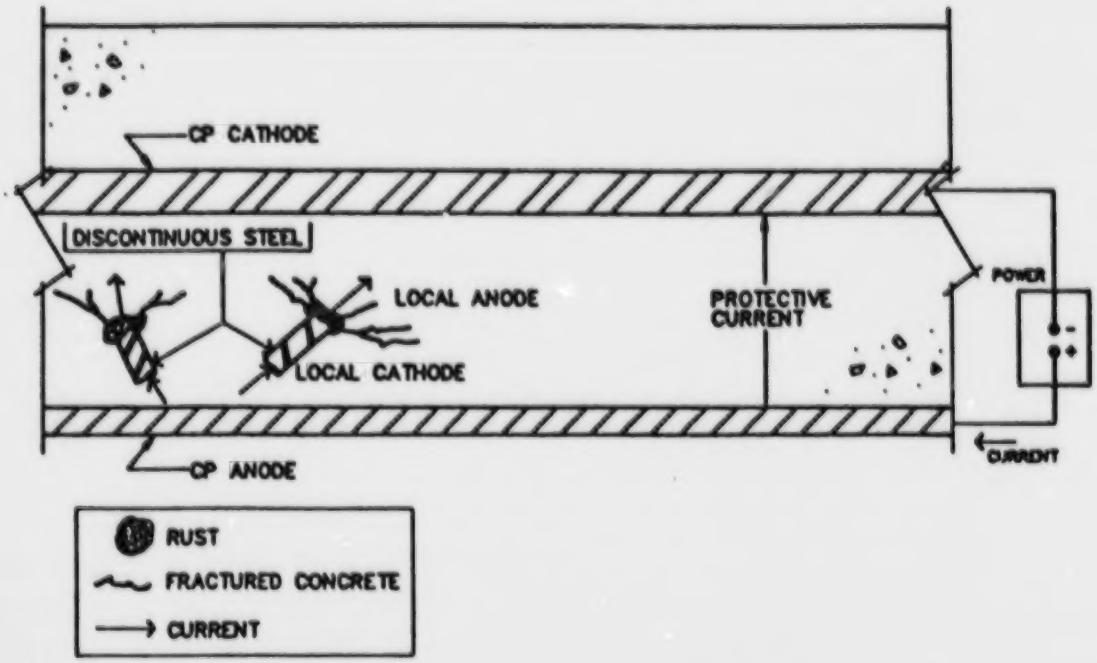



FIG. 6. CORROSION OF DISCONTINUOUS STEEL IN IMPRESSED CATHODIC PROTECTION SYSTEM

protection performance after installation is to record changes in these corrosion potential readings. Standard half-cells of copper in a copper sulphate solution are the most common ones used, but silver and mercury based half-cells are also available.

### 2.3.2 Associated Repairs

The cathodic protection process does not restore the structural integrity of corrosion-damaged reinforced concrete, control water leakage, or improve drainage. These aspects of a repair program need to be addressed in conjunction with the cathodic protection installation. If protective current is to reach the steel, loose surface rust must be removed and steel must be encased in concrete. This requires that delaminations must be patched. Epoxy-coated steel is isolated from the corrosion process, and so will not "absorb" current (except at defects in the epoxy coating). Water leakage through slab cracks can damage the applied anode, and therefore the repair program must include waterproofing (either general or local).

### 2.3.3 Particular Data Requirements

The performance of cathodic protection depends upon various properties which are not typically considered in a structural condition survey. These include

- electrical continuity of steel
- extent of discontinuous metals or short circuits
- conductivity of concrete - both base and patch materials
- surface area of steel as a ratio of concrete surface area

These measurements must be taken by a qualified, and preferably independent, specialist if a comparison of repair options shows that cathodic protection would be a cost-effective alternative to consider. There are no standards to govern the procedures for taking these readings.

# 3. AVAILABLE SYSTEMS

## 3.1 General

The principles of cathodic protection have been employed for many years to control corrosion in various wet environments (such as underground tanks and pipelines). Cathodic protection has been used and monitored on reinforced concrete bridge decks for about 15 years; however the system used is too thick and heavy for most parking structures. The technology for application to parking structures is still in the development stage and there are no assembled data verifying the effectiveness or durability of available systems over their intended lifespan. Any parking garage installation must therefore be considered somewhat experimental. A list of suppliers is given in Appendix A.

## 3.2 Components

The basic components of a cathodic protection system for a parking structure are a power supply; the applied anode; reference electrode(s); the electrolyte (concrete); the cathode to be protected (the reinforcing steel); electrical connections between components; and control systems to govern the voltage and/or current output. The power supply will typically have several different output circuits, each supplying a separate section of the anode. The area of each section is limited in size to make fault location easier after system start-up and to limit the impact of a short circuit.

## 3.3 Top Surface/Bottom Surface Installation

The top surface of the slab is typically closest to the layer of steel with most corrosion activity, and thus should be the most efficient location for an anode. An anode applied to the top surface must resist exposure to traffic and moisture, either by itself or in conjunction with a separate wearing surface and/or membrane.

An anode applied to the bottom surface of the slab is protected from traffic; it can therefore be a less expensive material. However, most of the current from the bottom surface flows into the bottom layer of steel. The bottom surface also has the most exposure to discontinuous steel left in the forms during construction and to rebar supports.

## 3.4 Anode Types

### 3.4.1 Conductive Coatings

Systems based on conductive coating anodes use a relatively thin carbon or graphite-loaded paint applied to the bottom surface (soffit) of the slab to be protected. Current is distributed to the coating through wires (sometimes called primary anodes) set in the coating, which is called the secondary anode. The conductive paint is black; a light-coloured top-coat is therefore applied over it to improve light levels in the facility.

Conductive coating systems are lightweight and do not reduce headroom. Application and material costs are the lowest of available systems. There has generally been a long commissioning period required to isolate short circuits because the anode is applied to the bottom surface and because, as a liquid during application, the coating material can flow into cracks to create short circuits. The coatings and their bond to concrete can be adversely affected by the acid which can be generated at the anode.

The carbon in the conductive coating is consumed in the anodic reaction, resulting in a theoretical service life which is proportional to the thickness of the coating. The service life of 15 years commonly indicated by system suppliers is based upon the estimated consumption rate of the carbon at design anode current densities. All the factors which affect the service life have not yet been identified.

### 3.4.2 Titanium Mesh in Mortar

For these systems, a diamond-shaped mesh of coated titanium 1 mm-thick is set in a layer of mortar applied to the top surface of the slab. Distribution of the current from the power supply is either through the mesh only or through conductors connected to the different sections of mesh. The mesh is held in place with plastic cleats and covered with a layer of a latex-modified mortar.

Laboratory tests indicate that the mesh material should have a service life of over 50 years. The durability of the mortar exposed to the anode current density is not known but is the subject of some concern and investigation. The chemical reaction at the anode is affected by the type of reactive metal coating, which affects the amount of acid production. The anode and mortar are relatively expensive to both purchase and apply. Repairs to the anode require chipping into the mortar, increasing examination and repair costs.

### 3.4.3 Conductive Polymer Mesh in Concrete

This anode material is made from a conductive polymer, blended with carbon, extruded over a copper wire. A mesh formed by fastening individual wires together is anchored to the concrete and covered with a layer of mortar. These anodes are more flexible and rugged than titanium mesh and can be installed on uneven surfaces. The carbon in the conductive polymer is consumed in the anode reaction and the conductor becomes brittle with time. The durability of the mesh connectors is being questioned. This system is typically more expensive than the titanium anodes, restricting its application.

### 3.4.4 Conductive Membrane

The concept of combining the anode with a waterproofing membrane is intuitively appealing; however, the quantity of carbon required to make a membrane conductive tends to make it relatively porous and brittle. Both liquid-applied and preformed sheet membranes are in development. There are small trial installations in operation but no performance data have been made available and no system has been widely marketed yet.

# 4. PERFORMANCE EVALUATION

## 4.1 Delamination Measurement

The only direct measure of system performance is whether or not delamination of the concrete continues to occur. As delamination formation can take several years, it is necessary to have other short-term tests to measure the effectiveness of cathodic protection.

## 4.2 Electrical Measurements

The effectiveness of cathodic protection is theoretically related to the amount of current flowing at a given voltage. In the concrete/steel system, however, there is too much variability in the electrolyte to measure this relationship directly. Therefore, criteria based upon corrosion potential readings are used to measure performance. Only through experiments and long-term measurements of installations can suitable criteria be established that predict actual in situ performance. A consensus in the relatively new field of parking structure protection will require collection and evaluation of laboratory and field studies over the next several years.

The criterion which is presently most commonly used is called potential decay or depolarization. Corrosion potentials are measured at several locations on the concrete surface with a half-cell. Readings are taken immediately after turning the system off (to measure the potentials of the reactions which are occurring with the system switched on but without the applied voltage), and then four hours after the system is shut off. At present, a shift (decay) of 100mV between these readings is believed to represent effective protection. Several hundred readings are taken over the surface, and it has yet to be established how many have to shift and whether only the readings in areas which were originally corroding have to undergo this shift. Long-term validation is still required.

The significance of variations in humidity and temperature levels, which affect the half-cell readings on different dates, has not been established.

### 4.3 Durability

Only systems using conductive coatings and a system using a polymer mesh anode have much history. A list of Canadian installations is given in Appendix B. As system performance has not been statistically analysed and published, it must be accepted that effective service life can only be estimated at this time.

### 4.4 Technical Support

If cathodic protection is to be used, experienced personnel must be available to keep the system functional. In a developing field, very few such people are available, and this may restrict the initial use of cathodic protection.

### 4.5 Cost

Initial application costs vary from about $\$40/m^2$ to about $\$80/m^2$ (1990). The longer term costs of maintenance and operation will only be known with confidence after several systems have been operational for many years.

# 5. IMPLEMENTATION AND OPERATION

## 5.1 Standards

Various bodies, including the Canadian Standards Association (CSA), National Association of Corrosion Engineers (NACE), National Reinforced Concrete Cathodic Protection Association (NRCCPA) and the Concrete Society (British) are trying to develop standards for use in specifying cathodic protection. As these have not yet received general recognition, systems cannot be evaluated for conformance with industry standards.

## 5.2 Monitoring

The physical performance testing of a system should be carried out by a specialist independent of the supplier. The frequency and, therefore, cost of these tests will vary between installations. To protect the owner, the installation contract should cover these costs and any connections required to the system for a suitable period. Most installations now have computer based monitoring programs which allow some basic operating parameters, such as voltage and current output, to be checked and even adjusted from a terminal linked to the facility by telephone. On-site measurements of corrosion potentials and delaminations are still required.

## 5.3 Staff Training

The facility maintenance staff must be made aware of the procedures to be used when working in the vicinity of the cathodic protection systems. Cleaning, painting, sprinkler testing and lighting maintenance or modification could all have impacts on the system. Site personnel should also be trained in routine observation of the system for evidence of conditions which should be addressed by the installation or maintenance company.

# APPENDIX A
## LIST OF SYSTEM SUPPLIERS FOR PARKING STRUCTURES

### A.1 Conductive Coatings

a) **Name:** DuoDac 85
**Anode:** Carbon in Solvent-Based Co-Polymer Acrylic Anode
**Manufacturer/Supplier:**
Corrosion Service Company Limited
369 Rimrock Road
Downsiview, Ontario
M3J 3G2
Phone: (416) 630-2600
Fax: (416) 630-2393/8161
Tlx: 06-218984

b) **Name:** Electrodag 8050 or RW 23698
**Anode:** Carbon in Water-Based Acrylic Resin Anode
**Manufacturer/Supplier:**
Acheson Colloids Company
P.O. Box 611747
Port Huron, Michigan
48061-1747
Phone: (313) 984-5581
Fax: (313) 984-1446
Twx: (810) 231-5265

**Canadian Distributor:**
Corexco Inc.
622 Avenue Meloche
Dorval, Quebec
H9P 2P4
Phone: (514) 636-0085

c) **Name:**
**Anode:** Solvent-Based
**Manufacturer/Supplier:**
Royston Laboratories Inc.
128 First Street
Pittsburgh, PA
15238
Phone: (412) 828-1500
Tlx: 86-5541

Canadian Distributor: Can-Con Gas Services Ltd.
101, 9333-45 Avenue
Edmonton, Alberta
T6E 5Z7
Phone: (403) 436-1937

d) Name: Electro-Coat 30-86
Anode: Carbon in Water-Based Polymer Anode
Manufacturer/Supplier: Passcorr Cathodic Systems Limited
521 Piercy Road
Unit 7
Bolton, Ontario
L7E 5B5
Phone: (416) 857-0583

e) Name: Sprayed Zinc
No Suppliers

A.2 Titanium Mesh in Mortar

a) Name: Tectrode
Anode: Platinized Expanded Titanium Mesh
Manufacturer/Supplier: ICI Americas Inc.
Wilmington, Delware
19897
Phone: (302) 575-3708
Fax: (302) 984-5010

b) Name: Lida Net
Anode: Metal Oxide Coated Expanded Titanium Mesh
Manufacturer/Supplier: Dow Chemical U.S.A./Oranzio de Nora S.A.
400 West Sam Houston Parkway South
P.O. Box 3387
Houston, Texas
77253-3387
Phone: (713) 978-3925
Fax: (713) 978-3930
Tlx: 775437

c) **Name:** Elgard Anode Mesh
**Anode:** Metal Oxide Coated Titanium Strip or Expanded Mesh Anodes
**Manufacturer/Supplier:** Elgard Corporation (div. of Eltech Co.)
470 Center Street
Chardon, Ohio
440224
Phone: (216) 285-1439
Fax: (216) 285-1408

## A.3 Conductive Polymer Mesh in Concrete

a) **Name:** Perex
**Anode:** Conductive Polymer Cable/Mesh Anodes
**Manufacturer/Supplier:** Elgard Corporation (division of Eltech Co.)
470 Center Street
Chardon, Ohio
44024
Phone: (216) 285-1439
Fax: (216) 285-1408

## APPENDIX B

## KNOWN PARKING STRUCTURE INSTALLATIONS

The following is a list of known installations of cathodic protection systems in Canada. They are listed in order of year of known (first) installation.

The following abbreviations are used:

1. Ach. = Acheson Colloids (Coating)
2. Capp. = Cappar Products (Coating)
3. Corex = Corexco Inc.
4. CorServ = Corrosion Services Ltd.
5. Pass = Passcorr Cathodic Systems Ltd.
6. Roys = Royston Laboratories Inc.
7. Raychem = Raychem Corp.

| DATE | SITE | SYSTEM(S) | APPROX.AREA CP |
|---|---|---|---|
| 1981 | PSAC Building Ramp, Ottawa | Wires in Slabs | 120m$^2$ |
| Aug.1982 | Manulife, Toronto, Ont. | Pass./Ach. | 1,000m$^2$ |
| Aug. 1984 | Louisburg, Quebec | Pass/Ach. | 3,400m$^2$ |
| Nov.1984 | Dufferin Mall, Toronto, Ont. | Raychem | 500m$^2$ |
| Mar.1985 (1986/88) | Guardian Towers, Toronto, Ont. | Pass./Ach./Capp | 8,000m$^2$ |
| Aug.1985 | Sutton Place, Toronto, Ont. | Pass./Ach. | 900m$^2$ |
| Oct.1985 | Dundas St., Toronto, Ont. | CorServ | 200m$^2$ |
| Sept.1985 (Nov.86) | Place Bell Mall, Ottawa, Ont. | Pass./Ach. | 16,000m$^2$ |
| Dec.1985 | Charles St.W., Toronto, Ont. | Pass./Ach. | 3,200m$^2$ |
| Apr.1986 | Benvenuto Place, Toronto, Ont. | Pass./Ach. | 1,000m$^2$ |
| Aug.1986 | Brentwood Towers, Toronto, Ont. | Pass./Ach. | 17,000m$^2$ |
| Sept.1986 | 50 Baif Blvd., Richmond Hill, Ontario | CorServ | 10,000m$^2$ |
| Oct.1986 | 80 St. Clair Ave.W., Tor., Ont. | Pass./Ach. | 4,000m$^2$ |

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| Dec.1986 (1987) | Main St. W., Hamilton, Ontario | CorServ | 8,800m$^2$ |
| Dec.1986 | Carlton St., Toronto, Ontario | CorServ | 1,000m$^2$ |
| Jul.1987 | Prudential Dr., Scar., Ont. (Disconnected) | CorServ | 500m$^2$ |
| Nov.1987 | Blackthorn Dr., Toronto, Ont. | CorServ | 7,000m$^2$ |
| Nov.1987 | William St., Oshawa, Ontario | CorServ | 8,000m$^2$ |
| Nov.1987 | Rathburn St., Mississauga, Ont. (Disconnected) | CorServ | 200m$^2$ |
| 1987 | 5 Brahms, Don Mills, Ontario | Pass. | 300m$^2$ |
| Apr.1988 | Bayview Ave., Toronto, Ontario | CorServ | 200m$^2$ |
| June 1988 | L'Hotel Classic, Laurier Blvd. St. Fois, Quebec | CorServ | 4,500m$^2$ |
| Sept.1988 | Wellesley St., Toronto, Ont. | CorServ | 6,500m$^2$ |
| Sept.1988 | Graydon Hall, Don Mills, Ont. | | 5,300m$^2$ |
| Sept.1988 | Don Mills Rd., Don Mills, Ont. | CorServ | 1,600m$^2$ |
| Dec.1988 | Eastdale, Toronto, Ontario | CorServ | 6,000m$^2$ |
| 1988 | Delta Chelsea Hotel, Tor., Ont. | Pass. | |
| 1988 | Place d'Youville, Hull, Quebec | Corex/Roys | 25,000m$^2$ |
| 1988 | Society D'Insurance D'Health Hull, Quebec | Corex/Roys | 2,000m$^2$ |